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(54) **Recombinant phages capable of entering host cells via specific interaction with an artificial receptor**

(57) The invention relates to a genetically modified bacteriophage, pseudovirion or phagemid capable of entering a host cell by binding of its artificial ligand to an artificial receptor present on said host cell. The invention

relates also to the use of the genetically modified bacteriophage, pseudovirion or phagemid and of the host cell to screen sequence libraries, including antibody library.

EP 1 088 892 A1

**Description**

**[0001]** The present invention relates to a recombinant bacteriophage, pseudovirion or phagemid that is capable of entering bacteria by specific binding to an artificial receptor. Said receptor does not comprise at its active binding site elements such as proteins or peptides that are derived from the natural receptor used in the specific initial bacteriophage - bacterium interaction.

**Background of the invention**

**[0002]** Bacteriophages, like bacteria, are very common in all natural environments. Bacteriophages (phages) are intracellular parasites. Bacteria and their phages have a common evolutionary history and phages may have adapted to their host species by multiple mechanisms. The phage genome may consist of double-stranded DNA, single-stranded DNA, double-stranded RNA or single-stranded RNA. Bacteriophages exist in several morphologies and can be spherical, cubic, filamentous, pleomorphic or tailed. Based on their life cycle, bacteriophages can be divided into three groups: the virulent phages capable of only lytic propagation (called lytic phages), the so-called temperate phages capable of either lytic propagation or lysogenic phase and the non-lysing phages where the mature phage is continuously extruded. The virulent life cycle of wild type phages consists of infection of the host cell, i.e. attachment to a specific receptor in the bacterial cell wall, followed by entering of the phage genome in the cell, replication of the phage genome, production of the phage structural components, phage assembly and release of the progeny phages after lysis of the host cell. In the lysogenic life cycle, the phage genome exists as a prophage resulting in coexistence of phage and host cell without lysis. Usually, this is achieved by integration of the phage genome into the bacterial chromosome. The life cycle of the non-lysing phages, like e.g. Bacteriophage M13, is similar to that of the lytic phages, but the infection is not followed by lysis.

**[0003]** Bacteriophages have been extensively used in biotechnology.

**[0004]** Phage genes or complete phages may be used to obtain lysis and/or killing of bacteria.

**[0005]** US4637980 describes the use of an *E. coli* strain containing defective temperature sensitive lambda lysogens as a method for cell disruption. Smith and coworkers (Smith *et al.*, 1987, *J. Gen. Microbiol.* 133: 1111-1126) describe the use of bacteriophages to treat diarrhoea in calves, caused by seven different bovine enteropathogenic strains of *E. coli*. WO95/27043 describes a method to treat infectious diseases caused by several bacterial genera, such as *Mycobacterium*, *Staphylococcus*, *Vibrio*, *Enterobacter*, *Enterococcus*, *Escherichia*, *Haemophilus*, *Neisseria*, *Pseudomonas*, *Shigella*, *Serratia*, *Salmonella* and *Streptococcus*, comprising the administration of bacteriophages with delayed inactivation by the animal host defence system. WO 98/51318 describes a diagnostic kit and a pharmaceutical composition, comprising bacteriophages to diagnose and to treat bacterial diseases caused by bacteria, such as *Listeria*, *Klebsiella*, *Pneumococcus*, *Moraxella*, *Legionella*, *Edwardsiella*, *Yersinia*, *Proteus*, *Helicobacter*, *Salmonella*, *Chlamydia*, *Aeromonas* and *Renibacterium*.

**[0006]** Another application of bacteriophages is the *in vitro* selection of proteins displayed on the tip of filamentous phages on immobilised target (= biopanning), which is a powerful technique for the isolation of interacting protein-ligand pairs from large libraries, such as antibody libraries (for a recent review: Rodi and Makowski, 1999, *Curr. Opin. Biotechnol.*, 10: 87-93). However, for optimal *in vitro* biopanning, a purified target protein is needed. Moreover, high quality of the library is a prerequisite for success. Enrichment for selfligated vector, phages carrying incomplete sequences, incorrect reading frames, deletions and amber stop codons are very often observed (Beekwilder *et al.*, 1999, *Gene*, 228, 23-31 and de Bruin *et al.*, 1999, *Nature Biotechnology*, 17: 397-399). In the search to avoid the problems encountered with panning using imperfect libraries, several alternative techniques, both bacteriophage based and non bacteriophage based, have been developed. Non bacteriophage based techniques are, amongst others ribosome display (Dall'Acqua and Carter, 1998, *Curr. Opin. Struct. Biol.*, 8: 443-450) and the yeast two-hybrid system (Drees, 1999, *Curr. Opin. Chem. Biol.*, 3: 64-70). Bacteriophage based techniques comprise display on phage lambda, SIP (Spada and Pluckthun, 1997, *Biol. Chem.*, 378: 445-456; EP0614989) and CLAP (Malmberg *et al.*, 1997, *J. Mol. Biol.*, 273: 544-551; WO9710330). SIP and CLAP are *in vivo* selection techniques and have the advantage that the F<sup>+</sup> *E. coli* host cells can only be infected by bacteriophages or pseudovirions when a matched pair is formed. Both systems are based on the fact that pilin on the F-pili of *E. coli* cells serve as the natural receptor for binding of the D2-domain of pIII from the phage (Deng *et al.*, 1999, *Virology*, 253:271-277). This results in retraction of the pilus, so that an interaction between the D1 domain of pIII with the TOL protein complex located in the *E. coli* cell membrane leads to the infection (Deng *et al.*, 1999, *Virology*, 253: 271-277). SIP has the disadvantage that it only works for high affinities of the binding pairs and that each target needs to be cloned, expressed and purified as a fusion with the D2 domain of pIII. Therefore, with SIP, normally only one target can be screened at the time. For CLAP only small peptides (15-18 amino acids) can be expressed on the F-pilus, hence, this technique can only be used for small linear epitopes. An additional disadvantage is the need for modified M13 to avoid natural infection of host cells. Therefore, removal of the D2 domain of pIII is essential. This results in a truncated form of M13 and concomitant difficulties to obtain good titres.

**[0007]** It is known that bacteriophages use specific receptors on the host cell wall as a way to recognise the host cell and to start the infection process. In all the applications cited above, the propagation of phages, pseudovirions or phagemids is dependent on the use of the natural phage receptor, or part of it, on the host cell wall. For M13, mainly used in these systems, the natural receptor is pilin (Malmborg *et al.*, 1997, *J. Mol. Biol.* 273: 544-551). Other examples of natural receptors are lamB for bacteriophage lambda (Werts *et al.*, 1994, *J. Bacteriol.* 176: 941-947), the outer membrane protein OmpA for bacteriophages K3, Ox2 and M1 (Montag *et al.*, 1987, *J. Mol. Biol.*, 196: 165-174), the outer membrane proteins OmpF and Ttr for bacteriophage T2 (Montag *et al.*, 1987, *J. Mol. Biol.*, 196: 165-174), the outer membrane protein OmpC for the T4 phage family (T4, Tula, Tulb) (Montag *et al.*, 1990, *J. Mol. Biol.*, 216: 327-334). The T4 bacteriophage family is using a C-terminal region of protein 37 as natural ligand (Montag *et al.*, 1990, *J. Mol. Biol.*, 216: 327-334), bacteriophages T2, K3, Ox2 and M1 are using protein 38 as natural ligand (Montag *et al.*, 1987, *J. Mol. Biol.*, 196: 165-174) whereas phage lambda is using the C-terminal portion of the lambda tail fibre protein as natural ligand (Wang *et al.*, 1998, *Res. Microbiol.*, 149: 611-624). Bacteriophage - receptor independent phage binding to mammalian cells expressing the growth factor receptor ErbB2 followed by receptor mediated endocytosis was also described: Marks and collaborators (Poul and Marks, 1999, *J. Mol. Biol.*, 288: 203-211 and Beccheril and Marks, 1999, *Biochem. Biophys. Res. Commun.*, 255: 386-393) successfully isolated phage capable of binding mammalian cells expressing the growth factor receptor ErbB2 and undergoing receptor mediated endocytosis by selection of a phage antibody library on breast tumour cells and recovery of infectious phage from within the cell. However, the phage could not propagate in the mammalian cell, and the detection of the cells carrying bacteriophage could only be realised in an indirect way, by expression green fluorescent protein as a reporter gene.

### **Summary of the invention**

**[0008]** One aspect of the invention is a genetically modified bacteriophage, pseudovirion or phagemid that is not dependent upon its natural receptor or parts thereof for entering a host cell.

**[0009]** Another aspect of the invention is a genetically modified bacteriophage, pseudovirion or phagemid capable of entering a host cell by specific binding to an artificial receptor. These artificial receptors can be endogenous host cell proteins located at the bacterial surface, or parts thereof, that are normally not involved in the bacteriophage - bacterium interaction, but it may also be heterologous proteins, preferentially fusion proteins displaying an oligo- or polypeptide on the bacterial surface. The genetically modified bacteriophage, pseudovirion or phagemid binds to the artificial receptor preferentially by an artificial ligand. A specific embodiment is a genetically modified bacteriophage that is not dependent upon OmpA, OmpC, OmpF, Ttr or pilin for interaction with and/or entering *E. coli*. A further specific embodiment is a genetically modified M13 bacteriophage, pseudovirion or phagemid that does not depend upon pilin, or fragments thereof for specific interaction with and/or entering of *E. coli*. Said M13 bacteriophage, pseudovirion or phagemid can enter both F<sup>+</sup> and F<sup>-</sup> *E. coli* cells, dependent upon an artificial receptor that is displayed on the surface of said cells.

**[0010]** Still another aspect of the invention is a bacteriophage, pseudovirion or phagemid that enters the host cell mediated by an antigen - antibody reaction, whereby in the binding complex no proteins or parts of the natural receptor are involved.

**[0011]** A preferred embodiment of the invention is a genetically modified M13 phage, pseudovirion or phagemid displaying an antibody, preferentially the variable part of a camel heavy chain antibody for instance disclosed in international patent application WO 94/04678 and in Hamers-Casterman C *et al* Nature, vol 363, 3 June 1993, p 446-448, on its tip, which can enter an *E. coli* host cell, displaying the antigen, preferentially as an pOprI fusion protein. The use of OprI as a protein for the expression of an amino acid sequence at the surface of the cell wall of a host cell is disclosed for example in international patent application WO 95/04079 which is incorporated herewith by reference.

**[0012]** A further aspect of the invention is the use of said bacteriophage, pseudovirion or phagemid for selective entering of a subpopulation of bacteria. Using the specific artificial receptor interaction, in a mixed culture, the bacteriophage, pseudovirion or phagemid will only enter those bacteria that carry said artificial receptor. By this, the subpopulation of bacteria can be identified and/or eliminated. One embodiment of the invention is the specific elimination of pathogenic bacteria by directing a recombinant bacteriophage, pseudovirion or phagemid to a specific bacterial surface protein of said pathogenic bacteria. The pathogenic bacteria can be gram positive, gram negative or gram variable and can belong, amongst other to the genera *Aeromonas*, *Chlamydia*, *Edwardsiella*, *Enterobacter*, *Enterococcus*, *Escherichia*, *Haemophilus*, *Helicobacter*, *Klebsiella*, *Legionella*, *Listeria*, *Moraxella*, *Mycobacterium*, *Neisseria*, *Pneumococcus*, *Proteus*, *Pseudomonas*, *Renibacterium*, *Salmonella*, *Serratia*, *Shigella*, *Staphylococcus*, *Vibrio* or *Yersinia*, without that this summation is limitative.

**[0013]** Elimination can be obtained by the lytic cycle of the bacteriophage, but is not limited this method. Other methods of eliminating the host cell may be the production of a toxic product encoded by the recombinant bacteriophage genome in the host cell. A preferred embodiment is the production of barnase placed after an inducible promoter, such as the barnase - barstar cassette described by Jucovic and Hartley (*Protein engineering*, 8: 497-499, 1995).

[0014] Another aspect of the invention is a host cell, entered by the genetically modified bacteriophage, pseudovirion or phagemid. Such host cell comprises the nucleotide sequence encoding the artificial receptor and the nucleotide sequence encoding the artificial ligand. Such sequences may be expressed in the host cell in combination with marker sequences, especially sequences encoding antibiotic resistance genes. A preferred embodiment is an *E. coli* cell, preferentially transformed with a plasmid encoding a pOpri-fusion protein, more preferentially transformed with a plasmid derived from ptrc-Opri, carrying a genetically modified M13 phage, pseudovirion or phagemid, preferentially a pK7C3 derived phagemid, wherein said genetically modified M13 phage is modified, especially by in vitro construction, with a nucleotide sequence encoding a protein capable of specifically binding to the pOpri-fusion protein.

[0015] In a particular embodiment of the invention, the Opri-fusion protein is carried out in introducing the nucleotide sequence of the fusion partner acting as the region for interaction with the ligand expressed on the bacteriophage, pseudovirion or phagemid, especially as disclosed in WO 95/04678.

[0016] Still a further aspect of the invention is the use of said bacteriophage, pseudovirion or phagemid to identify interacting proteins, including cases where none of the members of the interacting protein is known.

[0017] In different embodiments, the bacteriophage, pseudovirion or phagemid can be used to screen (1) a host cell, displaying a bait against a library of bacteriophages, pseudovirions or phagemids displaying the preys, (2) a bacteriophage, pseudovirion or phagemid displaying a bait against a library of host cells displaying the preys, (3) a library of bacteriophages, pseudovirions or phagemids displaying different preys or baits against a library of host cells, displaying different baits or preys (As illustrated in Figure 1).

[0018] A preferred embodiment is where pOpri is used as fusion partner for the display of bait or prey on the surface of the F<sup>-</sup> *E. coli* strains (Williams & Meynell 1971. Mol. Gen. Genet. 113: 222-227) such as DH5 $\alpha$  and UT5600 as host cell and where the phagemid pK7C3 is used for cloning the prey or bait as a pIII fusion protein.

[0019] Another embodiment of the invention is the construction of a subtraction library, with the use of lytic bacteriophages, preferentially barnase expressing bacteriophages. In this embodiment, a part of the host cell library is recognised by lytic phages such as barnase expressing phages and killed upon recognition of the artificial receptor by the artificial ligand, entering of the bacteriophage, pseudovirion or phagemid and expression of the lytic gene.

[0020] Another aspect of the invention is a method for selecting artificial receptor - artificial ligand interactions, comprising

- growing a host cell or a mixture of host cells displaying one or more artificial receptors,
- contacting said host cell or said mixture with a genetically modified bacteriophage, pseudovirion or phagemid or a mixture of genetically modified bacteriophages, pseudovirions or phagemids with one or more artificial ligands,
- selecting those cells that have been entered by one or more bacteriophages, pseudovirion or phagemid.

[0021] One embodiment of the invention is said method, whereby the selection is based on an antibiotic resistance marker. Another embodiment is said method whereby the cells are selected by killing of the host cell, preferentially by expression of barnase. A preferred embodiment is said method, whereby the host cell is an *E. coli* cell, displaying the artificial receptor as a pOpri fusion protein, and the genetically modified bacteriophage, pseudovirion or phagemid is a genetically modified M13, displaying an artificial ligand as a pIII fusion protein.

## Definitions

[0022] The following definitions are set forth to illustrate and define the meaning and scope of the various terms used to describe the invention herein.

### Genetically modified bacteriophage:

[0023] a bacteriophage of which the genome has been modified, at least by the introduction of the gene encoding for an artificial ligand. This introduction can be as a replacement of one of the endogenous genes or as an additional gene besides the endogenous genes.

### Natural receptor:

[0024] protein domain, protein or protein complex situated on the host cell wall, involved in the natural initial interaction between a bacteriophage and said host cell, whereby this interaction is followed by introduction of the genetic material of the bacteriophage into the host cell.

Artificial receptor:

**[0025]** protein domain, protein, fusion protein or protein complex on the host cell wall, whereby said protein domain, protein, fusion protein or protein complex does not contain one or more peptide fragments of at least 10 contiguous amino acids derived from the natural bacteriophage receptor in the protein sequence or region that is involved in the interaction between bacteriophage, pseudovirion or phagemid and the artificial receptor.

Protein :

**[0026]** encompasses peptide, protein, glycoprotein, lipoprotein or another form of modified protein, including chemically modified protein.

Protein complex:

**[0027]** protein - protein complex, but also protein - compound complex, whereby said compound may be any chemical or biological compound, including simple or complex inorganic or organic molecules, peptido-mimetics, carbohydrates, nucleic acids or derivatives thereof.

Natural ligand:

**[0028]** protein, protein domain or protein complex of the bacteriophage, pseudovirion, or phagemid involved in the natural initial interaction between said bacteriophage, pseudovirion, or phagemid, and a host cell, including recognition of and possibly binding to the natural receptor, whereby this interaction is followed by introduction of the genetic material of the bacteriophage into the host cell.

Artificial ligand:

**[0029]** protein, protein domain or protein complex of the bacteriophage, pseudovirion, or phagemid, whereby said protein domain, protein, fusion protein or protein complex does not contain one or more peptide fragments of at least 10 contiguous amino acids derived from the natural ligand of the bacteriophage in the protein sequence or region that is involved in the interaction between bacteriophage, pseudovirion or phagemid and the artificial receptor.

Host cell:

**[0030]** any bacterial cell that can allow a bacteriophage, pseudovirion or phagemid to enter said cell after interaction of a said bacteriophage, pseudovirion or phagemid with a natural or artificial receptor. As example, host cells include gram-negative or gram-positive bacteria, especially including E coli cells and in particular F<sup>-</sup> cells which do not permit entering of bacteriophages, pseudovirions or phagemids through the pillin mechanism.

Entering bacteria:

**[0031]** means that the bacteriophage, pseudovirion or phagemid can enter as a whole or as a part (e.g. only the genetic material) the host cell after specific binding to the artificial receptor. The mechanism by which the material is entering the host cell is not limited to specific ways and can be amongst others an active infection process or a passive uptake by the host cell. Methods for determination of the specific binding of the artificial ligand with the artificial receptor are illustrated in the examples.

Specific binding:

**[0032]** means that the initial step of the entering is mediated by a specific interaction between the artificial receptor on the host cell wall and the artificial ligand of the bacteriophage, pseudovirion or phagemid. This specific interaction is preferentially a protein - protein interaction. This entering after specific interaction should be distinguished from the Calcium dependent pilus independent infection that can be detected with M13 bacteriophages in which the second N-terminal domain of gIIIp has been removed (Kreber *et al.*, 1997, *J. Mol. Biol.* 268: 607-618).

**[0033]** According to particular embodiments, the invention relates to a genetically modified host cell, transformed with a nucleotide sequence encoding an artificial receptor in conditions enabling that the artificial receptor be expressed at the surface of the host cell, said host cell being further transformed with a nucleotide sequence encoding said artificial ligand whereby said nucleotide sequence encoding the ligand entered the host cell as a consequence of the interaction

between said artificial ligand and a protein sequence or region on said artificial receptor.

**[0034]** Particular genetically modified host cells are those wherein the nucleotide sequence encoding the artificial receptor and/or the nucleotide sequence encoding the artificial ligand are not initially known.

**[0035]** According to another specific embodiment, the genetically modified host cell is a gram-negative bacterium, especially an *E. coli* cell of the F<sup>-</sup> type.

**[0036]** According to another particular embodiment, the genetically modified host cell is a transformed cell wherein the nucleotide sequences of the artificial receptor and the nucleotide sequence for the artificial ligand are respectively coding sequences of an antibody or a functional fragment thereof and coding sequence of an antigen, or are respectively coding sequences of an antigen and coding sequence of antibody or a functional fragment thereof.

**[0037]** In said genetically modified host cell of the invention, the functional antibody fragment can be a variable fragment of an antibody, encompassing four-chain antibodies or two-chain antibody as defined in international patent application WO 94/04678, including native or modified, especially truncated chains thereof. In a preferred embodiment the variable chain is a VHH fragment of a camelid antibody or a functional portion of said VHH, as disclosed in the above cited patent application which is incorporated by reference.

**[0038]** The invention relates also to the above defined genetically modified host cell, wherein the nucleotide sequence encoding the artificial receptor comprises a sequence encoding OprI or a part of OprI sufficient to enable the exposure, at the surface of the host cell, of a protein sequence or region capable of interacting with the artificial ligand.

**[0039]** A further object of the invention is a kit comprising a genetically modified host cell according to the above proposed definitions and specific embodiments or comprising a host cell and/or a bacteriophage, pseudovirion or phagemid and/or means including a cloning vector enabling the construction of said host cell and/or a bacteriophage, pseudovirion or phagemid according to the above definitions.

**[0040]** A particular kit is designed to be used for *in vivo* panning of antibody or antibody fragment library, or antigenic sequences library.

**[0041]** Said kit can also be used for the simultaneous *in vivo* panning of both an antibody fragment library, and an antigenic sequences library.

**[0042]** The invention therefore provides means for the identification of target sequences or molecules including especially amino acid sequences capable of interacting with a determined receptor, whether the nature or sequences of said receptor is known or unknown. Especially the invention can be used for the identification of therapeutic targets.

### Short description of the Figures

**Figure 1** gives a schematic representation of the screening of a proteome expression library against a camel VHH anti-proteome antibody library. **Figure 2:** schematic representation of phagemid pK7C3. **Figure 3:** schematic representation of plasmid ptrc-OprI

### [0043]

**Figure 4:** Results of the Western blot. From left to right: lane 1 shows the molecular weight markers. Lane 2 and 3 show the total lysate of *E. coli*, transformed with ptrc-OprI, respectively after growth in LB (lane 2) and M9 (lane 3). Lane 4 and 5 show the total lysate of *E. coli*, transformed with ptrc-OprI- OVA, respectively after growth in LB (lane 4) and M9 (lane 5). Proteins are visualised with anti-OprI, as described in example II.

**Figure 5 (a and b):** Schematic representation of barnase activation by inversion of the expression cassette, due to integrase activity induced by heat shock.

### Examples

#### Example I: Construction of M13 pseudovirions displaying Camel Heavy Chain antibodies (VHH)

##### Immunisation of camels

**[0044]** A camel (B) was immunised with 1 mg hen-egg ovalbumin (Sigma) in the presence of complete Freund adjuvant, and boosted in the presence of incomplete Freund adjuvant at days 7, 14, 28, 35 and 42.

Anticoagulated blood was collected for lymphocyte isolation on day 45. This results in VHH library CAMELB

##### Construction of phagemid library

**[0045]** Peripheral blood lymphocytes were prepared using Unisep (WAK Chemie, Germany). The camelid heavy

chain antibodies (VHH's) from  $10^7$  lymphocytes were cloned after RT-PCR amplification in the NcoI-NotI site of the pK7C3 vector (Figure 2) and transformed in TG1 (Lauwereys *et al*, 1998, *the EMBO Journal*, 17 : 3512-3520). The primers for the amplification are

CATGCGATGACTCGCGGCCAGCCGGCCATGGC and  
GTGTGCGGCCGCTGAGGAGACRGTGACCWG.

**[0046]** The pK7C3 vector is a pHEN4 (Ghahroudi *et al*, 1997, *FEBS letters*, 414: 521-526) derivative where the ampicillin resistance gene was replaced by the chloramphenicol resistance gene and the haemagglutinin tag was replaced by a histidine and c-myc tag (Ghahroudi *et al*, 1997, *FEBS letters*, 414: 521-526)

#### Construction of M13 pseudovirions displaying camel VHH

**[0047]** VHH's from the CAMELB library were expressed on phage after infection of the library with M13KO7 helper phage (pK7C3-VHHB) as described by Ghahroudi *et al*, 1997, *FEBS letters*, 414: 521-526. A library of  $3 \times 10^6$  individual colonies was obtained of which 85% had the correct insert size, and 90% of these could produce a fusion protein between VHH and pIII.

#### Selection of ovalbumin specific pseudovirions by biopanning

**[0048]** The CAMELB library was panned for the presence of binders on ovalbumin coated in wells of microtitre plates (10 µg ovalbumin / well). Bound phages were eluted and allowed to infect TG1 cells (Stratagene). After two or three rounds of panning, individual colonies were grown, periplasmic extracts were prepared and screened for the presence of ovalbumin binders in ELISA. (Skerra and Pluckthun, 1988, *Science*, 240: 1038-1041). The plasmid of these binders was prepared and sequenced. We obtained 2 VHH binders of which 1DBOVA1 (DVQLVESGGGSVPAGSLRLSCAVSGYTYENRYMAWFRQAPGKEREGVAAIWR GGNNPPYADSVKGRFTISQDNAKNIVSLLMNSLKPEDTAIYYCAAQAGRFSGLPY ESTYDYWGQGTQVTVSS) was the most abundant.

#### Titre determination

**[0049]** The titre of the phages was determined by incubation of 150 µl TG1 (F<sup>+</sup>) cells at OD<sub>600nm</sub>= 0.5 with 10 µl of phages of different dilutions, for 30 minutes at 37°C. This was plated on LB-agar plates containing 25 µg/ml chloramphenicol and 2% glucose.

**[0050]** The background for infection of DH5α (Gibco BRL) was determined under the same conditions as described above for TG1.

#### Preparation of the phages

**[0051]** Cultures of TG1 containing pK7C3-VHHB or 1DBOVA1 were grown at 37°C in 100 ml 2xTY medium containing 2% glucose, and 25 µg/ml chloramphenicol, until the OD<sub>600nm</sub> reached 0.5. M13KO7 phages ( $10^{12}$ ) were added and the mixture was incubated in a water bath at 37°C for 2 x 30 minutes, first without shaking, then with shaking at 100 rpm. The culture was centrifuged (15', 4300 rpm, room temperature). The bacterial pellet was dissolved in 600 ml of 2xTY medium containing 25 µg/ml chloramphenicol and 25 µg/ml kanamycin, and incubated overnight at 30°C, vigorously shaking at 250 rpm.

**[0052]** These overnight cultures were centrifuged for 15 minutes at 4300 rpm at 4°C. Phages were precipitated for 1 hour on ice with PEG (20% poly-ethylene-glycol and 1.5 M NaCl), pelleted by centrifugation (30', 4300 rpm, 4°C), dissolved in 10 ml PBS and centrifuged for another 10 minutes at 4300 rpm and 4°C. The supernatant was loaded on 2 ml Ni-NTA (QIAGEN), washed extensively with 50 mM Na<sub>2</sub>HPO<sub>4</sub>, 1M NaCl pH= 7.0, eluted with 50 mM NaAc, 1M NaCl pH= 4.5 and neutralised with 1 M Tris pH= 7.4. Phages were again PEG precipitated by immediate centrifugation for 30 minutes at 4300 rpm and 4°C after PEG addition. The pellet (invisible) was dissolved in 1 ml PBS + 100 µl PBS-caseine. 15% glycerol was added and the phages were stored at -80°C for maximally 1 week, until further use.

#### Example II: display of OprI and OprI-ovalbumin fusion protein on *E. coli*

**[0053]** The ptrc-OprI (Cote-Sierra *et al.*, 1998, *Gene*, 221:25-34; Figure 3) or ptrc-OprI-ova (obtained by amplifying

the gene encoding for hen-egg ovalbumin, digesting the product with BamHI and EcoRI and cloning the digest in BglII/EcoRI digested pE. coli Top10F' (Invitrogen) and tested for expression in M9CAA and LB-medium in Western blot. Cells were induced with 1 mM IPTG (Calbiochem) at OD<sub>600nm</sub> = 0.6 and grown overnight at 37°C on a rotary shaker at 200 rpm. Cells were centrifuged and concentrated 10-fold. Total cell lysates, obtained by sonication were loaded on a 12% SDS-PAGE and transferred to nitrocellulose for Western blotting. Transferred proteins were detected using a monoclonal anti-Opri antibody QB2 (De Vos D. et al, Journal of general microbiology 1993, 139: 2215-2223). An anti-mouse IgG conjugated with alkaline phosphatase (Sigma) was applied and the blots were developed with the BCIP/NBT substrate. The results are shown in Figure 4. A band at the position of intact fusion protein is clearly observed. However, large amounts of degradation products demonstrate the instability of the pOpri-ova form. Since these degradation products might interfere with the infection, conditions for growth and infection were optimised, amongst others by the use of UT5600 (F<sup>-</sup>, *ara-14*, *leuB6*, *azi-6*, *lacY1*, *proC14*, *tsx-67*, *entA403*, *trpE38*, *rfdD1*, *rpsL109*, *xyl-5*, *mtl-1*, *thi1*,  $\Delta$  *ompT*, *fepC266*) (Biolabs). UT5600 is an outer membrane protease T-deficient *E. coli* strain, which was used for the stable presentation of Ig scFv fusions (Maurer and Meyer, *J. Bacteriol.*, 1997, 179: 794-804).

#### Example III: receptor independent entering of *E. coli* by M13 pseudovirions.

**[0054]** Cultures of *E. coli* strain DH5 $\alpha$  containing pGene, 221: 25-34) or p\alpha{p600nm reached 0.6. Cells were centrifuged at 4300 rpm for 5 minutes and resuspended in the original volume and in the same medium (= washed cells\*). A fraction of the cells was induced with 1 mM IPTG and grown at 37°C for another 4 hours (\*\*).

**[0055]** To test the pilus independent entering of *E. coli* displaying ovalbumin on its surface by M13 phages displaying ovalbumin specific antibodies, we incubated 150  $\mu$ l of *E. coli* cells with 10  $\mu$ l phages from pK7C3-VHHB of different dilutions for 1 hour at 37°C without shaking.

**[0056]** Infection of *E. coli* was screened for by selection of incubation mixtures on LB-agar plates containing 100  $\mu$ g/ml ampicilline, 25  $\mu$ g/ml chloramphenicol and 2% glucose.

**[0057]** Individual colonies were screened in ELISA. Therefore, large single colonies (resistant to ampicilline and chloramphenicol) were inoculated in 10 ml TB medium containing 0.1% glucose, 100  $\mu$ g/ml ampicilline and 25  $\mu$ g/ml chloramphenicol for 8 hours. IPTG was added at a final concentration of 10 mM and the cultures were grown overnight at 37°C at 200 rpm.

**[0058]** Individual colonies in TG1 and DH5 $\alpha$  were picked and grown in 10 ml TB medium containing 0.1% glucose and 25  $\mu$ g/ml chloramphenicol for 4 hours. IPTG was added at a final concentration of 1 mM and the cultures were grown overnight at 28°C at 200 rpm.

**[0059]** Periplasmic fractions were prepared by pelleting the overnight cultures, and dissolving the pellet in 200  $\mu$ l TES (0.2 M Tris-HCl, pH= 8.0, 0.5 mM EDTA, 0.5 M sucrose). This was incubated on ice for 20 minutes. 300  $\mu$ l TES/4 was added and incubated at 4°C for 25 minutes. This suspension was centrifuged for 25 minutes at maximal speed in an eppendorf centrifuge and the supernatant was used for testing in ELISA.

**[0060]** Periplasmic fractions were tested in NUNC-plates coated overnight with ovalbumin (5  $\mu$ g/ml) or casein as a negative control (1% w/v in PBS) and blocked overnight with 1% (w/v) casein. Samples were incubated for 2 hours at room temperature and ovalbumin binding VHH's were detected with a mouse anti-Histidine-tag (SEROTEC), anti-mouse-alkaline phosphatase conjugate (Sigma) and a chromogenic substrate (Sigma). The results are summarised in Table I

Table 1:

The numbers indicate the number of positive clones in ELISA versus the number of clones that were tested. Extracts were scored positive if the OD<sub>405nm</sub> was at least double the OD of the background (coated caseine at 1%). Numbers separated by a comma are from independent experiments.

Table 1	Positives in ELISA
TG1	1/337
DH5 $\alpha$	0/7
DH5 $\alpha$ + ptrc-Opri	2/141
DH5 $\alpha$ {ptrc-Opri-OVA}	7/16, 17/38, 7/24
DH5 $\alpha$ {ptrc-Opri-OVA}, washed*	14/19

\*: The cells were washed 1 time with fresh medium before infection with phages as described above.



Table 1: (continued)

Table 1	Positives in ELISA
DH5 $\alpha$ {ptrc-Opri-ova} + IPTG**	3/12

\*\* Cells were induced with IPTG as described above.

Example IV: receptor independent entering of *E.coli* by pseudovirions is specific for the artificial receptor

[0061] 150  $\mu$ l of washed UT5600 containing ptrc-Opri-OVA (indicated as UT5600{ptrc-Opri-OVA}) or DH5 $\alpha$ {ptrc-Opri-OVA} cells at OD<sub>600nm</sub>= 0.6 were incubated with 10  $\mu$ l phages of pK7C3-VHHB of different dilutions for 1 hour at 37°C without shaking.

[0062] The same experiment was repeated after pre-incubation of the phages with 1 ml ovalbumin (2mg/ml) for 1 hour at room temperature. The phages were mixed with 150  $\mu$ l of washed UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells at OD<sub>600nm</sub>= 0.6 and incubated for 1 hour at 37°C.

[0063] This was plated on LB agar plates containing 25  $\mu$ g/ml chloramphenicol, 100  $\mu$ g/ml ampicilline and 2% glucose. Expression of 25-45 clones in UT5600 cells and DH5 $\alpha$  was carried out as described above.

[0064] The results are summarised in Table 2.

Table 2:

number of colonies on plates after infection of washed UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells with phages with or without pre-incubation with ovalbumin. Numbers separated by a comma are from independent experiments. c <sup>r</sup> : chloramphenicol resistant; a <sup>r</sup> : ampicilline resistant		
Table2	DH5 $\alpha$ c <sup>r</sup> , a <sup>r</sup>	UT5600 c <sup>r</sup> , a <sup>r</sup>
<i>E.coli</i> (ptrc-Opri-ova) + pK7C3-VHHB phages	150	90, 73
<i>E.coli</i> (ptrc-Opri-ova) + ovalbumin pretreated pK7C3-VHHB phages	1	2, 2

[0065] Infection of washed UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells with phages from pK7C3-VHHB pre-incubated with hen-egg ovalbumin protein, reduced the number of transformants significantly, which means that infection is dependent upon ovalbumin display on the host cell wall.

Example V: Survival of *E.coli* cells and phages upon coinubation

[0066] 150  $\mu$ l of washed UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells at OD<sub>600nm</sub>= 0.6 were incubated with 10  $\mu$ l phages of PK7C3-VHHB for 1 hour at 37°C without shaking.

[0067] This was plated on LB agar plates containing 25  $\mu$ g/ml chloramphenicol, 100  $\mu$ g/ml ampicilline and 2% glucose (C).

[0068] Cells were also checked for survival upon growth (A) and upon incubation with phages (B) by dilution and plating on LB agar plates containing 100  $\mu$ g/ml ampicilline and 2% glucose. The results are shown in Table 3.

Table 3:

Number of cells upon incubation of washed UT5600{ptrc-Opri-OVA}_or DH5 $\alpha$ {ptrc-Opri-OVA} cells with pK7C3-VHHB phages.		
Table3 number of cells	DH5 $\alpha$	UT5600
Before incubation (A)	2 x 10 <sup>8</sup>	10 <sup>9</sup>
After incubation (B)	5 x 10 <sup>7</sup>	3 x 10 <sup>8</sup>
entered (C)	64	150

[0069] The titre of pK7C3-VHHB phages was determined before incubation with washed DH5 $\alpha$ {ptrc-Opri-OVA} cells. Cells were centrifuged after incubation for 1 hour at 37°C and the supernatant was used to determine the titre of unentered phages. The titres were determined by incubation of 150  $\mu$ l TG1 cells at OD<sub>600nm</sub>= 0.5 with 10  $\mu$ l of phages of different dilutions for 30 minutes at 37°C. This was plated on LB-agar plates containing 25  $\mu$ g/ml chloramphenicol and 2% glucose. The number of transformants are listed in Table4.

Table 4:

Number of pK7C3-VHHB phages before and after incubation with washed DH5 $\alpha$ {ptrc-Opri-OVA} cells	
Table 4	number of phages
Before incubation	$5.6 \times 10^7$
After incubation	$1.2 \times 10^7$

[0070] UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells survived very well when incubated with and entered by pK7C3-VHHB phages. The pK7C3-VHHB phages which did not enter UT5600{ptrc-Opri-OVA} or DH5 $\alpha$ {ptrc-Opri-OVA} cells are still able to infect TG1 cells and are therefore stable under the conditions used.

Example VI: Individual *E.coli* cells displaying ovalbumin on the surface are entered by a single ovalbumin specific phage.

[0071] Positive clones were selected from experiment 2 for UT5600 (clone number 10, 11, 12, 13, 16, 17). They were inoculated in 5 ml LB containing 25  $\mu$ g/ml chloramphenicol, and grown overnight at 37°C. Plasmid was prepared, transformed in TG1 and plated on LB agar plates containing 25  $\mu$ g/ml chloramphenicol and 2% glucose. Individual colonies were tested in ELISA as described before (in TB containing 25  $\mu$ g/ml chloramphenicol and 0.1% glucose).

Table 5:

number of positive clones in ELISA versus the number of clones that were tested for individual colonies.	
Table 5	Positives in ELISA
10	8/8
11	8/8
12	8/8
13	7/8
16	8/8
17	8/8

[0072] Individual positive clones were selected and grown overnight for plasmid preparation. After transformation in TG1 individual colonies were tested in ELISA. All clones scored positive, therefore we can be sure that ovalbumin specific phages have entered the cell. Colony PCR on these individual colonies showed that they have the same length if they originate from the same original clone.

Example VII: Optimisation of the conditions of receptor independent entering

[0073] Cells of DH5 $\alpha$ {ptrc-Opri-OVA} and UT5600{ptrc-Opri-OVA} were grown at 37°C. A 150  $\mu$ l sample was removed at different time intervals, washed and  $5 \times 10^8$  phages of pK7C3-VHHB were added. This suspension was incubated for 1 hour at 37°C and plated on LB-agar plates with 2% glucose, 25  $\mu$ g/ml chloramphenicol and 100  $\mu$ g/ml ampicillin. Single colonies were tested in ELISA as described above. The results are shown in Table 6a and 6b.

UT5600, Table 6a			
Time of growth (minutes)	OD600 nm	tfu	Positives in ELISA pK7C3-VHHB
30	0.062	20	7/15
60	0.076	56	7/15
90	0.142	100	11/15,2/3
120	0.273	130	11/16
150	0.555	150	8/15

(continued)

UT5600, Table 6a			
Time of growth (minutes)	OD600 nm	tfu	Positives in ELISA pK7C3-VHNB
210	1.24	120	2/13
270	2.25	30	7/12

DH5 $\alpha$ , Table 6b			
Time of growth (minutes)	OD600 nm	tfu	Positives in ELISA pK7C3-VHNB
60	0.010	0	-
120	0.038	23	5/13
210	0.197	97	3/8
270	0.600	84	3/5
300	0.665	64	2/8

**Tables 6a and 6b:** Number of positive clones in ELISA versus the number of clones that were tested and the number of transformants (tfu) as a function of the OD600nm of the cells. Numbers separated by a comma are from independent experiments.

**[0074]** Cells of DH5 $\alpha$ {ptrc-Opri-OVA} and UT5600{ptrc-Opri-OVA} were grown at 37°C. Increasing concentrations of pK7C3-VHNB phages were added to 150  $\mu$ l of washed cells at OD600nm= 0.2-0.3 for UT5600{ptrc-Opri-OVA} and 0.6 for DH5 $\alpha$ {ptrc-Opri-OVA}. This mixture was incubated for 1 hour at 37°C and plated on LB-agar plates with 2% glucose, 25  $\mu$ g/ml chloramphenicol (Chl) and 100  $\mu$ g/ml ampicillin (Amp). Single colonies were tested in ELISA as described before.

UT5600, Table7a			
Number of phages added	Number of transformants on Amp/ Chl	Number of positives in ELISA	Number of positives in ELISA (%)
$7 \times 10^6$	30	0/2	-
$1 \times 10^7$	20	0/2	-
$7 \times 10^7$	85, 90, 150	0/5, 1/24, 2/24	-, 4, 8
$1 \times 10^8$	70	1/4	25
$4 \times 10^8$	67	4/29	14
$7 \times 10^8$	300, 300	18/24, 20/20	75, 100

DH5 $\alpha$ , Table7b			
Number of phages added	Number of transformants on Amp/ Chl	Number of positives in ELISA	Number of positives in ELISA (%)
$5 \times 10^7$	85	10/28	36
$2 \times 10^8$	250	21/43	49
$5 \times 10^8$	110	17/40	43

**[0075]** **Table7a-b:** Increasing concentrations of pK7C3-VHNB phages were mixed with 150  $\mu$ l UT5600{ptrc-Opri-

OVA) at OD<sub>600nm</sub> = 0.2-0.3 or with DH5α{ptrc-Opri-OVA} cells at OD<sub>600nm</sub> = 0.6. Individual colonies were tested in ELISA. Numbers separated by a comma are from independent experiments.

[0076] Optimal conditions for uptake of phages were tested by mixing pK7C3-VHBB phages with UT5600{ptrc-Opri-OVA} or DH5α{ptrc-Opri-OVA} cells at different optical densities. Individual colonies were tested in ELISA. For UT5600 {ptrc-Opri-OVA} the optimal density is between 0.15 and 0.3 and for DH5α{ptrc-Opri-OVA} between 0.2 and 0.6. UT5600 {ptrc-Opri-OVA} cells grow much faster than DH5α{ptrc-Opri-OVA} and are easier infected by anti-ovalbumin expressing phages (positive clones in ELISA) (73% versus 30-50% table6a-b). When increasing amounts of phages were mixed with UT5600{ptrc-Opri-OVA} cells (OD<sub>600nm</sub> = 0.2-0.3), more positive clones were obtained in ELISA (table7a). 75-100% positive clones were obtained when 5-10 x 10<sup>8</sup> phages were mixed with 0.5 x 10<sup>8</sup> UT5600{ptrc-Opri-OVA} cells resulting in 150-500 individual colonies. However, in DH5α{ptrc-Opri-OVA}, no increase in positive clones in ELISA was observed upon addition of increasing amounts of phages (table7b).

#### Example VIII: selective elimination by killer phages

[0077] Barnase is a extracellular ribonuclease from *Bacillus amyloliquefaciens* (Hartley & Rogerson 1972, Prep. Biochem. 2: 229-242). A very low level of intracellular expression of barnase in *E.coli* is lethal because bamase depolymerizes the RNA of its host. Jucovic & Hartley developed a tightly controlled system (pMI47a) for the intracellular expression of bamase in *E.coli* (*Protein engineering*, 8: 497-499, 1995). The plasmid encodes barstar (a strong polypeptide inhibitor of barnase) under the transcriptional control of the Tac promotor. A barnase gene (without secretion signal) has been cloned in the inverse orientation downstream from barstar. In pMI47a, the Tac promotor is followed by attP, followed by barstar, followed by the inversed gene for barnase, followed by attB. AttP and attB are derived from the phage lambda attachment site. pMI47a is not toxic for *E.coli* because it overproduces barstar and no barnase (OFF configuration, figure 5a). The Integrase protein (INT function) from phage lambda recognises the attB and attP sequences and inverts the DNA fragment that is located between the attB and attP sites *in vivo*. In the resulting plasmid pMI47b the Tac promotor is followed by attR, followed by barnase, followed by the inversed gene for barstar, followed by attL. Sites attR and attL are the products of recombination between attP and attB (Jucovic & Hartley, 1995, Protein Engineering 8: 497-499). This plasmid is toxic for *E.coli* because it produces active barnase in the cytoplasm of the host (ON configuration, figure 5b). The system can be switched *in vivo* from the OFF to the ON configuration in the *E. coli* strain D1210HP (supE44 ara14 galK2 lacY1 D(gpt-proA)62 rpsL20 (Str<sup>r</sup>) xyl-5 mtl-1 recA13 D(mrcC-mrr)HsdS<sup>-</sup> (rm<sup>-</sup>) lacI<sup>q</sup> LacY<sup>+</sup> lxis-kil-cl857) (Stratagene) by a short incubation at 42°C. This strain encodes the integrase function (Int; lxis) from phage lambda, whereas D1210 doesn't have this function.

[0078] A conditionally lethal phage particle was made by cloning the conditionally lethal cassette of pMI47a into a phagemid. A DNA fragment of pMI47a including the Tac promotor, followed by attP, followed by barstar, followed by the inversed gene for barnase, and followed by attB was amplified by PCR. This PCR product was cloned as a blunt end fragment within the EcoRI site of the pK7C3-1DBOVA1 vector (example I) to give pK7C3BB-1DBOVA1 (Before ligation, pK7C3-1DBOVA1 was linearized with EcoRI and filled-in with Klenow DNA polymerase).

[0079] Plasmids of pK7C3BB-1DBOVA1, pK7C3, ptrc-Opri-OVA and pMI47a were transformed in D1210 and D1210HP electrocompetent cells. Individual colonies were grown in LB with 25 µg/ml chloramphenicol or 100 µg/ml ampicilline and 2% glucose at 37°C until the OD<sub>600nm</sub> = 1.2-1.3. Half of the culture was exposed to thermal induction (15 minutes at 42°C). Both fractions (before and after induction) were spread after appropriate dilutions, on LB agar plates containing 25 µg/ml chloramphenicol or 100 µg/ml ampicilline and 2% glucose. The numbers of transformants were counted and are listed in table 8.

construct	<i>E.coli</i> strain	temperature	Number of transformants/ml
PMI47a	D1210	37°C	3 x 10 <sup>8</sup> Amp <sup>r</sup>
		37°C-42°C	2 x 10 <sup>8</sup> Amp <sup>r</sup>
	D1210HP	37°C	2 x 10 <sup>8</sup> Amp <sup>r</sup>
		37°C-42°C	280 Amp <sup>r</sup>
Ptrc-Opri-OVA	D1210	37°C	3 x 10 <sup>8</sup> Amp <sup>r</sup>
		37°C-42°C	2 x 10 <sup>8</sup> Amp <sup>r</sup>
	D1210HP	37°C	3 x 10 <sup>8</sup> Amp <sup>r</sup>
		37°C-42°C	2 x 10 <sup>8</sup> Amp <sup>r</sup>
pK7C3	D1210	37°C	5 x 10 <sup>8</sup> Chl <sup>r</sup>
		37°C-42°C	4 x 10 <sup>8</sup> Chl <sup>r</sup>
	D1210HP	37°C	6 x 10 <sup>8</sup> Chl <sup>r</sup>
		37°C-42°C	3 x 10 <sup>8</sup> Chl <sup>r</sup>
pK7C3BB-1DBOVA1	D1210	37°C	4 x 10 <sup>8</sup> Chl <sup>r</sup>
		37°C-42°C	3 x 10 <sup>8</sup> Chl <sup>r</sup>
	D1210HP	37°C	5 x 10 <sup>8</sup> Chl <sup>r</sup>
		37°C-42°C	560 Chl <sup>r</sup>

**Table8:** Number of transformants with or without thermoinduction of D1210 or D1210HP cells containing PMI47a, ptrc-Opri-OVA, pK7C3 or pK7C3BB-1DBOVA1.

**[0080]** The results show that D1210 cells (lacking the *Int* gene) transformed with PMI47a, ptrc-Opri-OVA, pK7C3 or pK7C3BB-1 DBOVA1 survive well upon thermoinduction, which indicates that PMI47a, ptrc-Opri-OVA, pK7C3 and pK7C3BB-1DBOVA1 are not harmful for *E.coli*. PMI47a, ptrc-Opri-OVA, pK7C3 and pK7C3BB-1DBOVA1 can be transformed and maintained in D1210HP if the cells are maintained at 37°C (OFF configuration). However, when cells are incubated at 42°C for 15 minutes (ON configuration), the integrase function is activated, and D1210HP cells containing PMI47a or pK7C3BB-1DBOVA1 do not longer survive. These experiments show that the phagemid pK7C3BB-1DBOVA1 is toxic for *E.coli* strain D1210HP if inversion is induced by thermoinduction of the *Int* gene. *Elimination upon recognition of an artificial receptor*

**[0081]** D1210 and D1210HP electrocompetent cells were transformed with ptrc-Opri-OVA. A single colony was used to inoculate a culture in LB containing 100 µg/ml ampicilline. Phages of pK7C3-1 DBOVA1 or pK7C3BB-1 DBOVA1 were prepared as described above. 150 µl of washed cells were incubated with 5 x 10<sup>8</sup> pK7C3-1DBOVA1 or pK7C3BB-1DBOVA1 phages for 1 hour at 37°C. Half of these mixtures was exposed to thermal induction (15 minutes at 42°C).

An aliquot (before and after induction) was spread on LB agar plates containing 25 µg/ml chloramphenicol and 100 µg/ml ampicilline and 2% glucose. The numbers of transformants were counted and are listed in table 9.

type of phages	<i>E.coli</i> strain	temperature	Number of transformants
pK7C3-1DBOVA1	D1210	37°C	8000
		37°C-42°C	7800
	D1210HP	37°C	8100
		37°C-42°C	8300
pK7C3BB-1DBOVA1	D1210	37°C	7800
		37°C-42°C	7900
	D1210HP	37°C	7600
		37°C-42°C	2

**Table9:** Number of transformants when D1210 or D1210HP cells containing ptrc-OprI-OVA were incubated with pK7C3-1DBOVA1 or pK7C3BB-1DBOVA1 phages with or without thermal incubation.

[0082] D1210HP cells displaying ovalbumin on their surface are killed by pseudovirions containing phagemid pK7C3BB-1 DBOVA1 after thermoinduction. This experiment clearly demonstrates that *coli* cells, expressing an artificial receptor can be recognised and killed by a bacteriophage with an artificial ligand that recognises the artificial receptor.

#### Example IX: Library versus library screening ("picup" screening)

[0083] Fission yeast (*Schizosaccharomyces pombe* p2, h<sup>+</sup>, arg<sup>3-</sup>, ura<sup>4+</sup>) was grown in YES medium (0.5% (w/v) yeast extract, 3.0% (w/v) glucose + 225 mg/l adenine, histidine, leucine, uracil and lysine hydrochloride). Cells were harvested by low speed centrifugation. 15 g wet cells were washed with 100 ml S-buffer (1.4 M sorbitol, 40 mM HEPES, 0.5 mM MgCl<sub>2</sub> adjusted to pH 6.5). After centrifugation the pellet was resuspended in 100 ml S-buffer containing 10 mM 2-mercaptoethanol and 1 mM PMSF and incubated at 30°C for 10 minutes. After centrifugation, the pellet was resuspended in 60 ml S-buffer containing 1 mM PMSF, and 460 mg Zymolase 20T (ICN Biomedicals) was added to prepare spheroplasts. After incubation for 3 hours at 30°C, the pellet was washed five times with 100 ml S-buffer containing 1 mM PMSF. Spheroplasts were resuspended in 60 ml Tris (25 mM, pH= 7.5), 100 mM NaCl, 2 mM EDTA supplemented with 1 tablet protease inhibitor mix (Boehringer) and lysed by two passages in French press. The supernatant was recovered after centrifugation for 30 minutes at 15.000 rpm in SS34 rotor. 15.5 g solid ammoniumsulfate was added to 30 ml of the supernatant. After incubation on ice for 1 hour, precipitated material was recovered by centrifugation and resuspended in 20 ml PBS. The solution was equilibrated in PBS by passage over PD10 columns. Following this treatment, the protein concentration was determined with Bio-Rad protein assay kit, using BSA as reference protein. Six aliquots, each 5 ml in volume, with a protein concentration of 8 mg/ml, were prepared for camel immunisation.

The immunisation and blood withdrawal scheme is as follows:

**[0084]**

- 5 Day 0 Collect preimmune serum  
 Day 0 inject subcutaneously 1 tube (40 mg protein) + complete freund adjuvant  
 Day 7 inject subcutaneously 1 tube + incomplete freund adjuvant  
 Day 14 inject subcutaneously 1 tube + incomplete freund adjuvant  
 Day 21 Collect anticoagulated blood and serum  
 10 Day 21 inject subcutaneously 1 tube + incomplete freund adjuvant  
 Day 28 inject subcutaneously 1 tube + incomplete freund adjuvant  
 Day 35 inject subcutaneously 1 tube + incomplete freund adjuvant  
 Day 38 Collect anticoagulated blood and serum

15 **[0085]** A cDNA library of *Schizosaccharomyces pombe* is constructed by recloning the *S.pombe* cDNA bank that is used in Two-hybrid system (Clontech). The cDNA inserts are amplified with specific primers harbouring restriction enzyme sites compatible for cloning into the multiple cloning site of ptc-Opri. The library is transformed in UT5600 or in D1210HP electro-competent cells.

20 **[0086]** The serum immunoglobulins from the immunised animal (day 21 or 38) are passed over protein A and protein G columns to purify the conventional antibodies and the heavy chain antibodies. Each fraction is used in a Western blot to evaluate the presence and titre of anti-*S.pombe* protein immunoglobulins.

**[0087]** Peripheral blood lymphocytes from the immunised camel are prepared using Unisep (WAK Chemie, Germany) from the anticoagulated blood isolated at days 21 and 42. The camel heavy chain antibodies (VHH's) from  $10^7$  lymphocytes are ligated after RT-PCR amplification in the SfiI-NotI sites of the pK7C3 or pK7C3-BB (pK7C3 with the barnase-barstar inversion system) vector and transformed in TG1 as described above, in order to obtain a library of  $10^8$  individual clones. The VHH phages is prepared by infection of the *E.coli* culture with M13K07 and enriched for virions with a VHH-gpIII fusion by IMAC chromatography (see before).

25 **[0088]** For the PICUP experiment,  $10^7$ - $10^8$  UT5600 cells from the cDNA library of *S.pombe* are mixed with  $10^{12}$  phages obtained from the camel VHH library. The mixture is incubated for 1 hour at 37°C and plated on LB agar plates containing 100 µg/ml ampicillin, 25 µg/ml chloramphenicol and 2% glucose. Colonies can only grow on this medium if the UT5600 cells are expressing a *S.pombe* antigen that is recognised and subsequently infected by a virion carrying an antigen-specific VHH. For each colony the VHH insert is sequenced with a primer annealing in the gene pIII sequence, while the cDNA coding for the antigen is directly sequenced with an Opri specific primer. The latter sequence is screened in a BLAST on the *S.pombe* genome sequence database to identify the gene. The specificity of the VHH (having a his-tag) is also tested in a Western blot in which the *S.pombe* extracted proteins are separated on SDS gels. The presence of the VHH is revealed with an anti-His monoclonal antibody (SEROTEC).

30 **[0089]** As a positive control, individual colonies from the cDNA library are used in a separate PICUP experiment. One single clone that is capable to produce a fusion protein with the lipoprotein (as seen by Western blot) is grown and challenged with the VHH phages from the library. The VHH from clones growing on Ampicilline and Chloramphenicol are induced with IPTG, extracted from the periplasm and it's binding to the yeast protein tested in Western blot and ELISA.

35 **[0090]** To eliminate particular antigens dominantly present in the matched pairs (*S.pombe* antigen - specific VHH) or particular VHH over-represented in the matched pairs, the killer phage strategy is used. To this end the UT5600 cells carrying the *S.pombe* cDNA library are incubated with the phages from the pK7C3-BB library of VHH. After infection the suspension is incubated at 42°C to eliminate the *E.coli* cells that are infected with phages. The surviving cells are carrying *S.pombe* antigens that are less frequent represented in the ptc-Opri or pK7C3-BB libraries. In a second step these surviving cells are used to inoculate fresh medium and to restart the PICUP experiment as before.

50 **Claims**

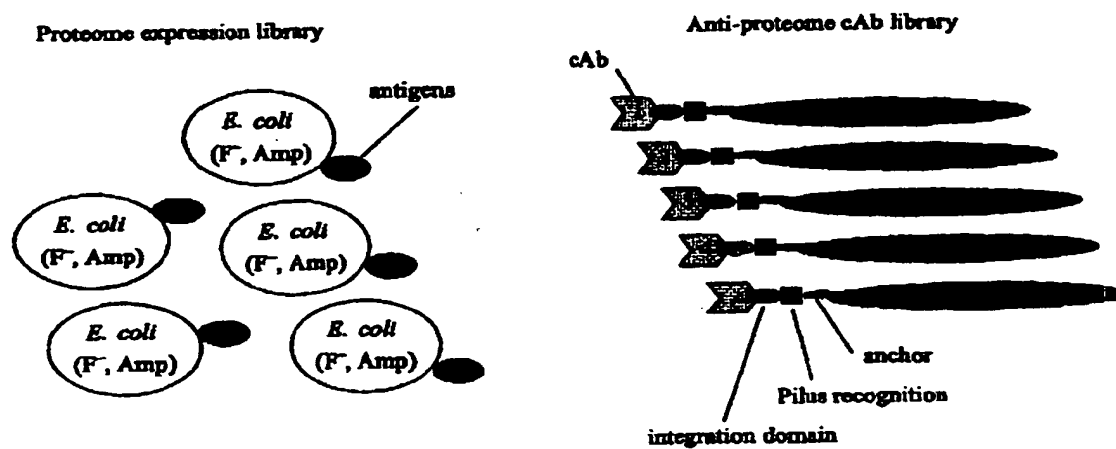
1. Genetically modified bacteriophage, pseudovirion or phagemid capable of entering a host cell by binding of its artificial ligand to an artificial receptor present on said host cell.
- 55 2. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1, carrying a nucleotide sequence encoding an artificial ligand, in condition enabling expression of said ligand at the surface of the bacteriophage, pseudovirion or phagemid.

3. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1 or 2, in which the artificial receptor is an endogenous cell wall protein of the host cell.
- 5 4. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1 or 2, in which the artificial receptor is a fusion protein whereby the protein sequence or region of said fusion protein, involved in the binding of the receptor with said bacteriophage, pseudovirion or phagemid is free of peptide sequences having 10 or more contiguous amino acid residues involved in the wild type bacteriophage-host cell interaction.
- 10 5. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1-3, where the binding is mediated by an antigen - antibody reaction.
6. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1-4, in which the said bacteriophage, pseudovirion or phagemid is lytic.
- 15 7. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 6, in which the entering in the host cell of said bacteriophage, pseudovirion or phagemid is inducing expression of barnase in the host cell.
8. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 1-7, where the bacteriophage is M13.
- 20 9. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 8, where the artificial ligand is a pIII fusion protein.
- 25 10. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 9, in which the phagemid is a pK7C3 derived vector
11. Genetically modified bacteriophage, pseudovirion or phagemid according to claim anyone of claims 1 to 4, in which the fusion protein is an pOrpl fusion protein.
- 30 12. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 11, in which the host cell is transformed with an ptrc-Opri derived vector.
13. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 12, in which the phagemid is a pK7C3 derived vector.
- 35 14. Genetically modified bacteriophage, pseudovirion or phagemid according to claim 5, in which the antibody is a camelid derived antibody, or is a functional fragment thereof, including a fragment comprising all or part of the VHH chain of a camelid heavy chain antibody.
- 40 15. Use of a bacteriophage, pseudovirion or phagemid according to claim 1-14 to detect and/or eliminate a specific bacterial population.
16. Use of a bacteriophage, pseudovirion or phagemid according to claim 1-14 to detect a artificial receptor- artificial ligand interaction.
- 45 17. Use of a bacteriophage, pseudovirion or phagemid according to claim 15 to screen an antigen and/or antibody library.
- 50 18. Method for selecting artificial receptor - artificial ligand interactions, comprising:
  - ♦ growing a host cell or a mixture of host cells displaying one or more artificial receptors,
  - ♦ contacting said host cell or said mixture with a genetically modified bacteriophage, pseudovirion or phagemid or a mixture of genetically modified bacteriophages, pseudovirions or phagemids with one or more artificial ligands,
  - 55 ♦ selecting those cells that have been entered by one or more bacteriophages, pseudovirion of phagemid.
19. Method for selecting artificial ligand-artificial receptor interactions according to claim 18, in which the host cell is transformed with an ptrc-Opri derived vector.



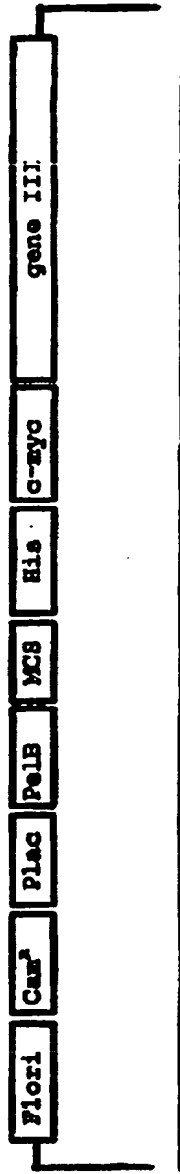
20. Method for selecting artificial ligand-artificial receptor interactions according to claim 18 or 19, in which the phagemid is a pK7C3 derived vector.
- 5 21. Genetically modified host cell, carrying a nucleotide sequence encoding an artificial receptor in conditions enabling that the artificial receptor be expressed at the surface of the host cell, said host cell being further transformed with a nucleotide sequence encoding said artificial ligand whereby said nucleotide sequence encoding the ligand entered the host cell as a consequence of the interaction between said artificial ligand and a protein sequence or region on said artificial receptor.
- 10 22. Genetically modified host cell according to claim 21, wherein the nucleotide sequence encoding the artificial receptor and/or the nucleotide sequence encoding the artificial ligand are not known.
23. Genetically modified host cell according to claim 21 or 22, which is a gram-negative bacterium, especially an E coli cell of the F<sup>-</sup> strain.
- 15 24. Genetically modified host cell according to any of claims 21 to 23, wherein the nucleotide sequences of the artificial receptor and the nucleotide sequence for the artificial ligand are respectively coding sequences of an antibody or a functional fragment thereof and coding sequence of an antigen, or are respectively coding sequences of an antigen and coding sequence of antibody or a functional fragment thereof.
- 20 25. Genetically modified host cell according to claim 24, wherein the functional antibody fragment is a VHH fragment of a camelid antibody or a functional portion of said VHH.
- 25 26. Genetically modified host cell according to anyone of claims 21 to 25, wherein the nucleotide sequence encoding the artificial receptor comprises a sequence encoding Opri or a part of Opri sufficient to enable the exposure, at the surface of the host cell, of a protein sequence or region capable of interacting with the artificial ligand.
- 30 27. A kit comprising a genetically modified host cell according to anyone of claims 21 to 26 bacteriophage, pseudovirion or phagemid according to anyone of claims 1 to 20, or comprising a host cell and/or a bacteriophage, pseudovirion or phagemid and/or a cloning vector enabling the construction of said genetically modified host cell according to anyone of claims 21 to 26.
- 35 28. A kit according to claim 27 for in vivo panning of antibody or antibody fragment library, or antigenic sequences library.
- 40 29. A kit according to claim 27 or 28, for the simultaneous in vivo panning of both an antibody fragment library, and an antigenic sequences library.
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- 55

**Figure 1: outline of the screening of an antigen - antibody library**



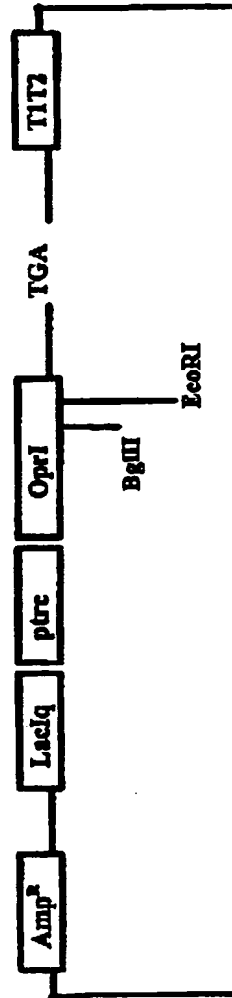
**Figure 2**

Phagemid: pK7C3



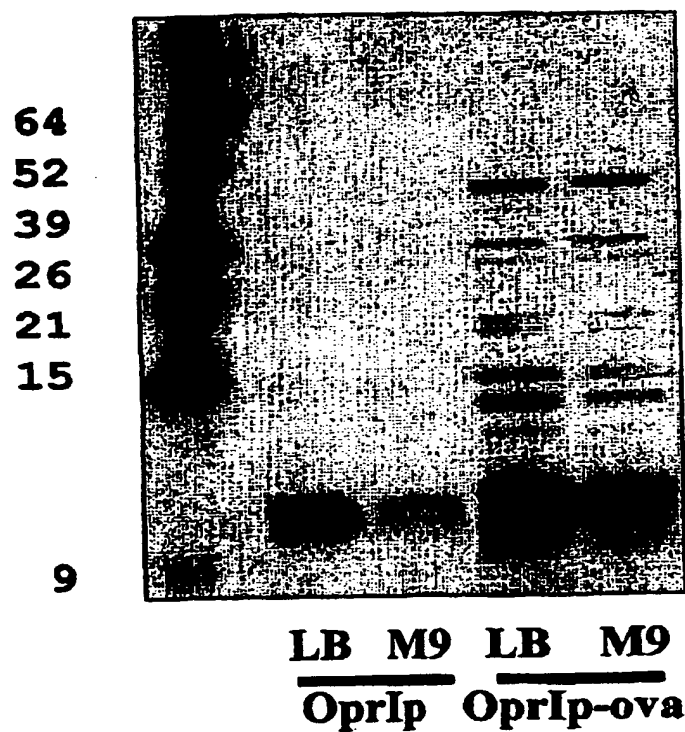
**Figure 3**

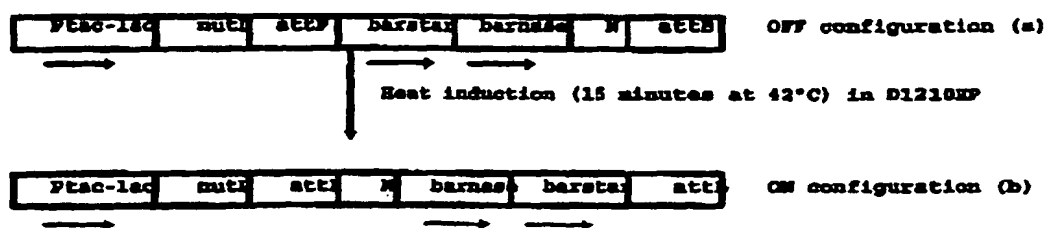
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**Figure 4: Results Western blot**

# **Expression of ovalbumin on the surface of the *E.coli* membrane**





**Figure 5a-b: bamase-barstar inversion cassette**



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 99 40 2348

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The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 29 November 1999	Examiner Panzica, G
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document</p> <p>T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons ----- &amp; : member of the same patent family, corresponding document</p>			

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The members are as contained in the European Patent Office EDP file on  
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